Aperture Optical Sciences

# Progress in Making X-Ray Optics

## NASA Mirror Tech Days

## July 31, 2012

Representative in North America and Europe for:

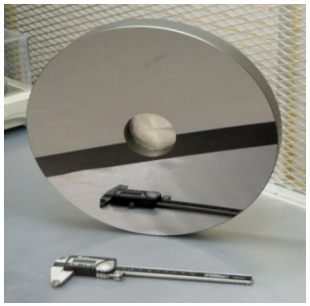
OKAMOTO optics

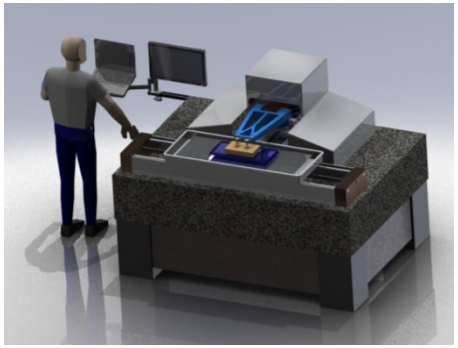
**Aperture Optical Sciences Inc.**
**27 Parson Ln, Unit G**
**Durham, Connecticut 06422**

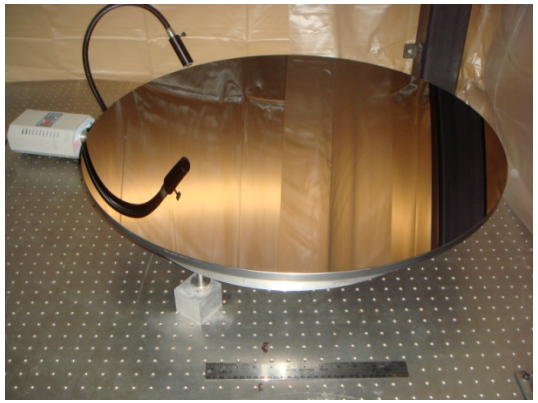
**Telephone: (860) 316-2589**
**Email: info@apertureos.com**
**Website: www.apertureos.com**

# Aperture Optical Sciences, Inc

- Aperture Optical Sciences Inc. founded in 2010 by Flemming Tinker and Kai Xin, www.apertureos.com
- Our Business focus is the manufacture of precision optics and manufacturing technology development.
- We are a team of 12 employees, located in Central Connecticut.
- This presentation is a collection of observations, solutions, and results in last 2 years plus the completion of two NASA SBIRs relating to XRAY optics finishing.







# XRAY Optics Place special demands on finishing technologies

- Non-revolving symmetry eliminates application of conventional spherical fabrication methods
- Surface finishing now done with sub-aperture polishing
  - Employs small tools and mathematical modification of removal rate to modify the figure.
  - Mid-spatial features are a  bi-product of the method
- Productivity is limited: tool to part ratio, control of environment
  - Large tool finishing has low convergence
  - Small tool finishing is limited by total volumetric removal

# AOS is developing a comprehensive fabrication process to control mid-spatial errors

Discussed at NASA Tech Days 2011

Surface Grinding

- Process Controlled CNC contour grinding

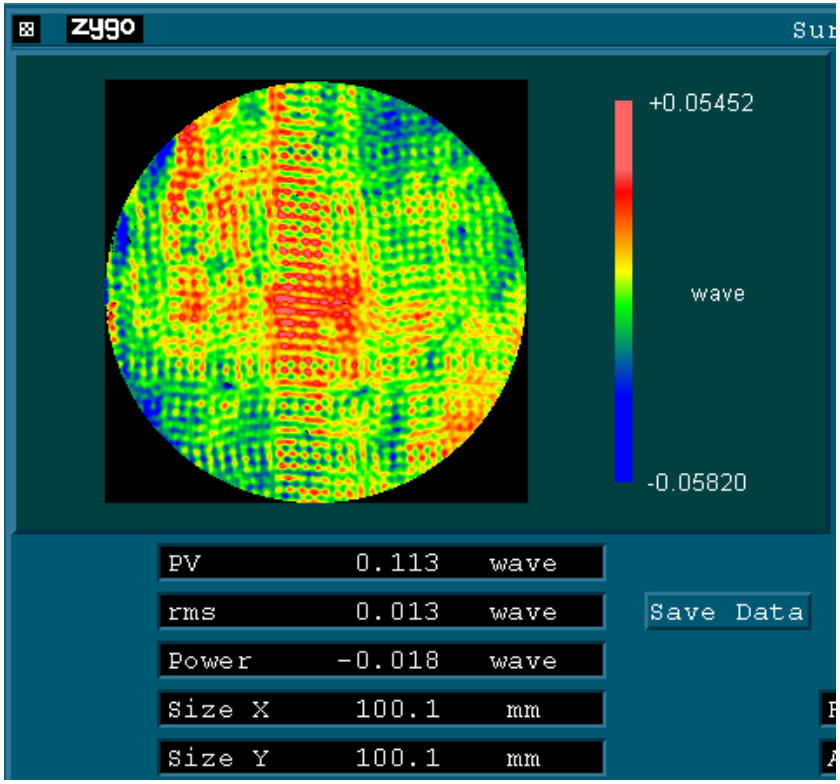
Mid-spatial Smoothing

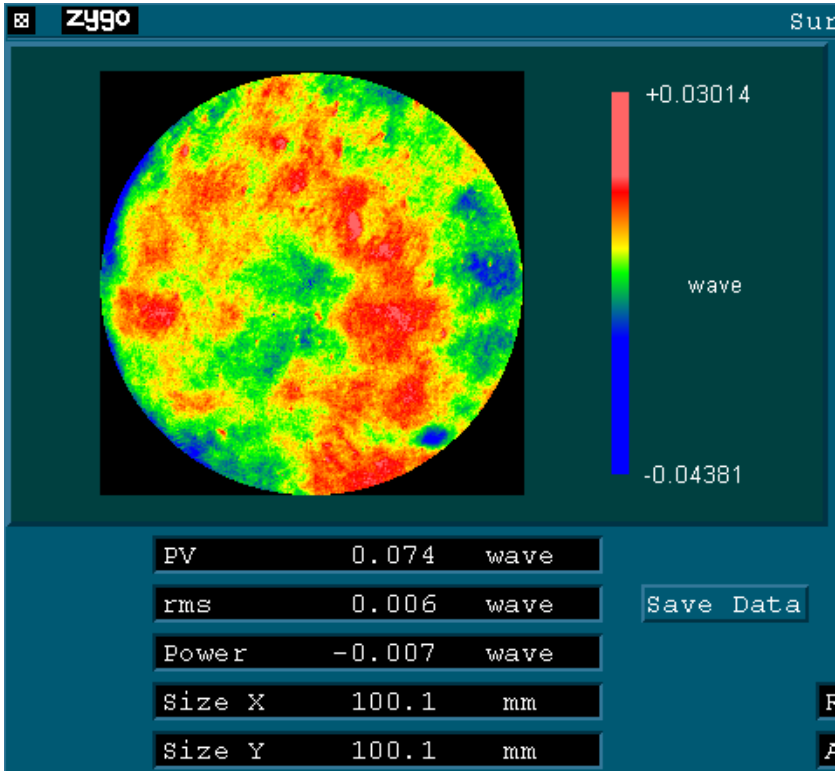
- AOS Proprietary Large tool conformal polishing

Corrective Polishing

This year, we'll present slope (gradient) specifications for surface finishing and recent polishing results we've obtained using last year's developments and this year's progress in robotic polishing

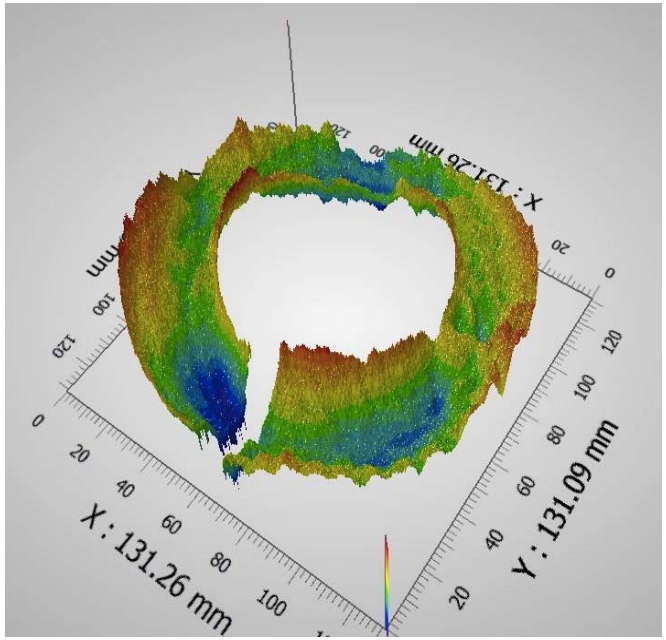
# Slope is highly depending on process

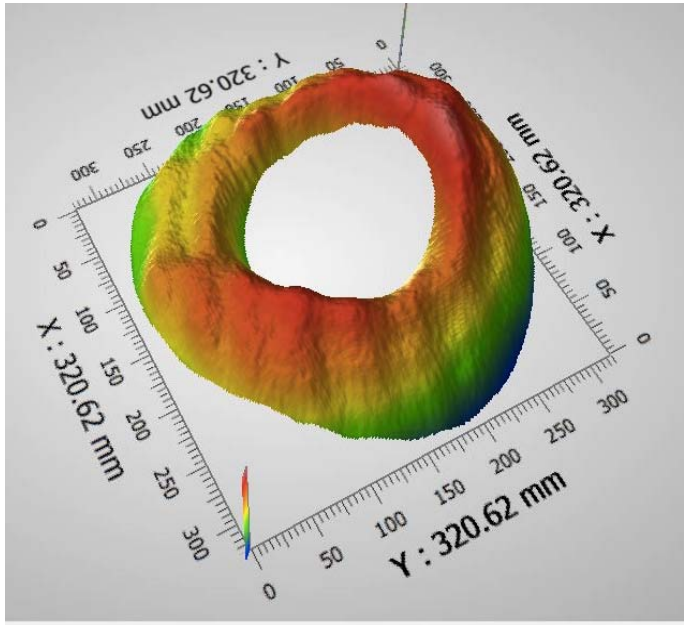



Same part, same machine, same size of sub-aperture tool, similar figure, different process, very different slope error.

# Surface Gradient (Slope) is a good discriminator



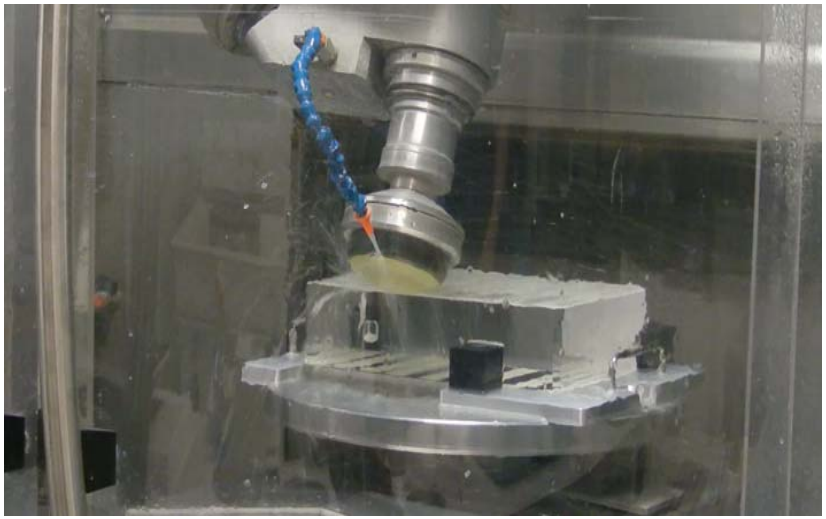




| | | |
|---|---|---|
| PV Form Error = 0.288λ | ≈ | PV Form Error = 0.267λ |
| RMS Form Error = 0.043λ | ≈ | RMS Form Error = 0.046λ |
| RMS Slope = 14.8 µrad | > | RMS Slope = 1.8 µrad |

# Low Gradient Surfaces Produced this year

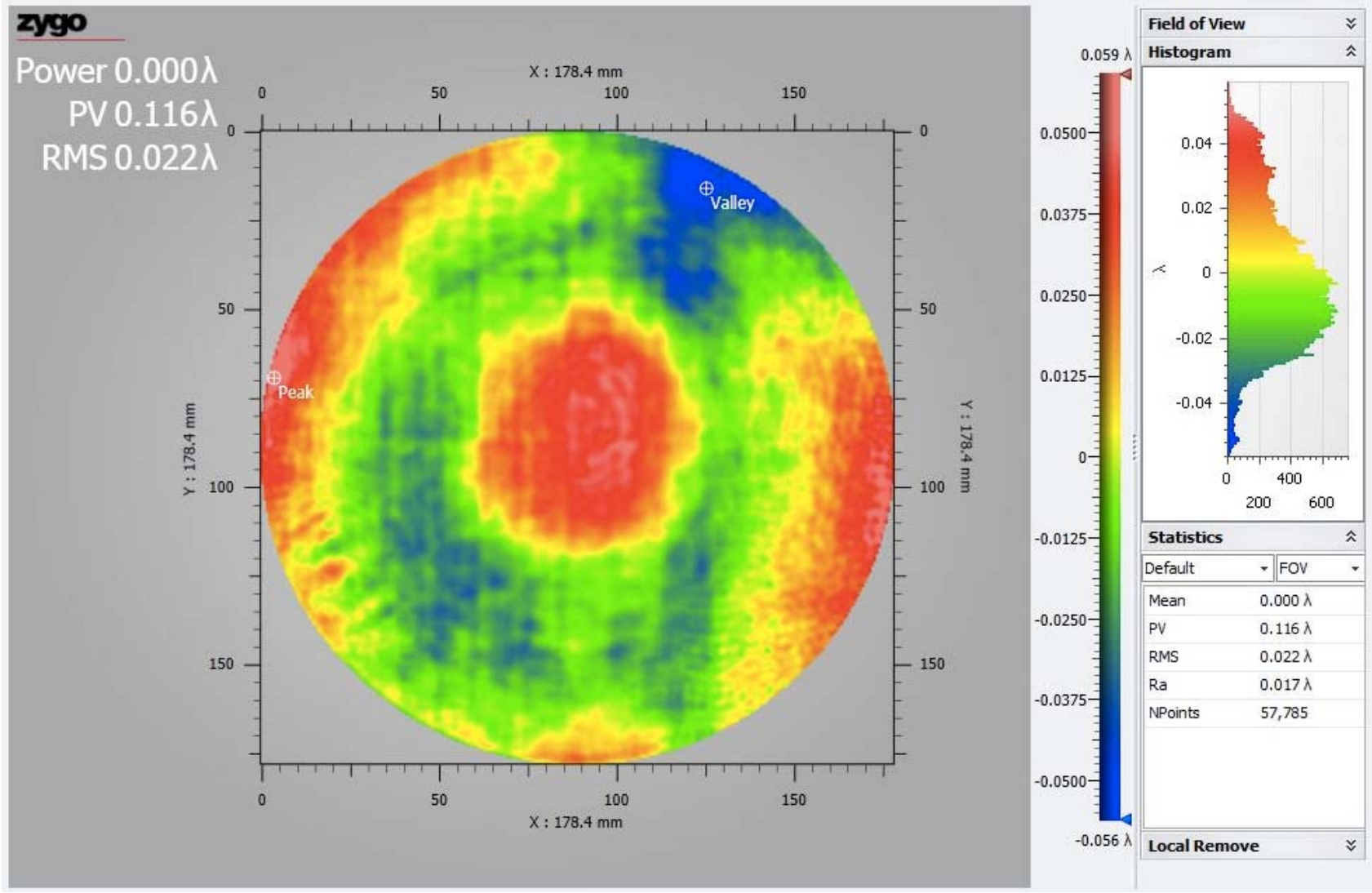
- Using robotic polishing (plus the developments we presented last year) we've produced low gradient surfaces with comparatively low mid-spatial periodic content

# AOS has effectively employed the Zeeko platform to perform aspheric grinding and polishing



- SBIRs helped AOS to verify and quantify the grinding model.
- Very low MSF from grinding has been achieved on both SiC and glass.
- 26 inch SiC asphere has been successfully ground with Zeeko platform.
- 600x400mm 90-degree OAP will be finished this summer.
- AOS will implement this low MSF grinding on a HAAS 64 inch machine to further improve its efficiency.

# Recent Results – F/45, 14 degree Parabola

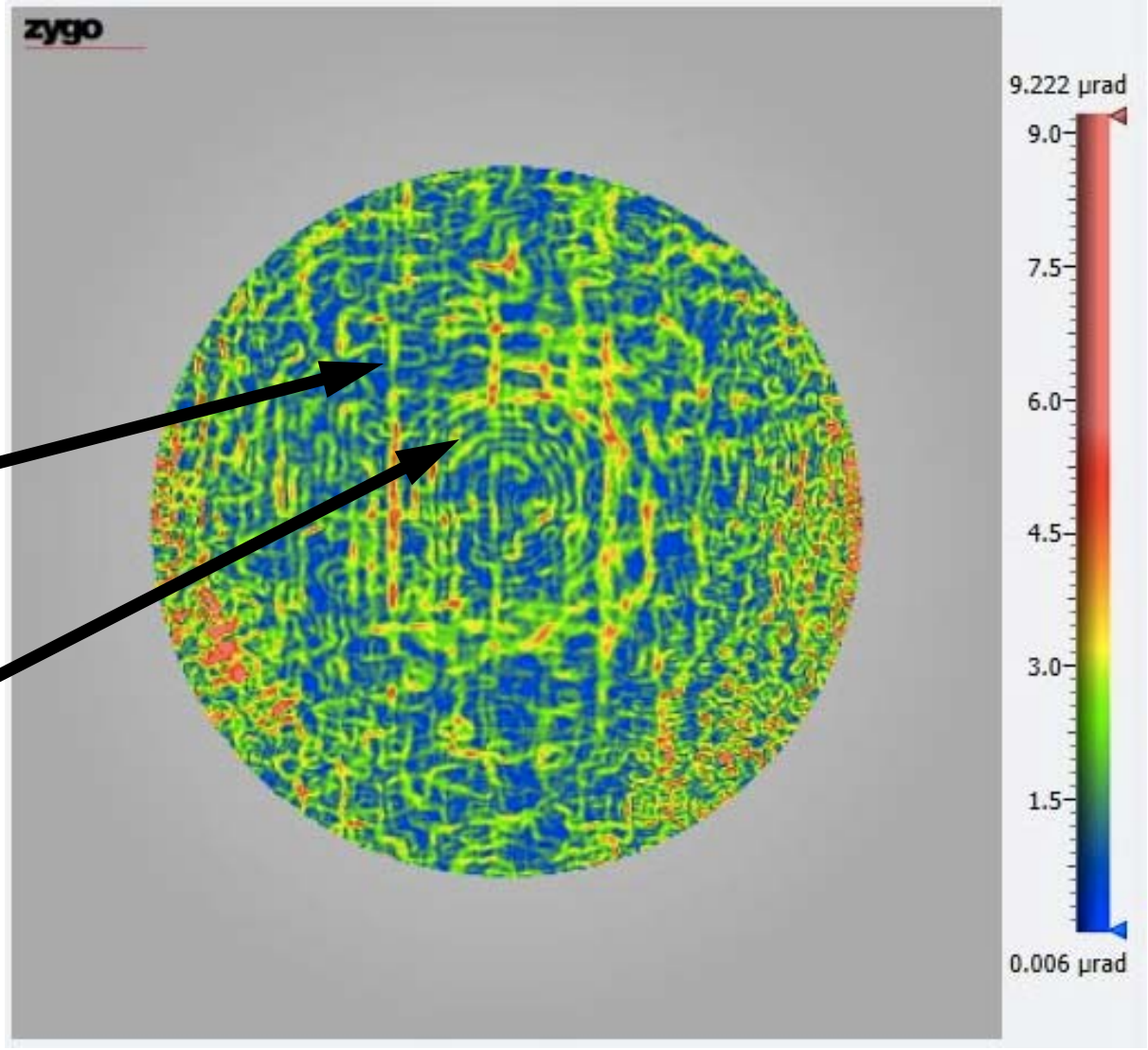


# Gradient Analysis of Final Result

**RMS Slope = 2.16 µrad**
(over full spatial capture range)

Polishing tool track marks (vertical)

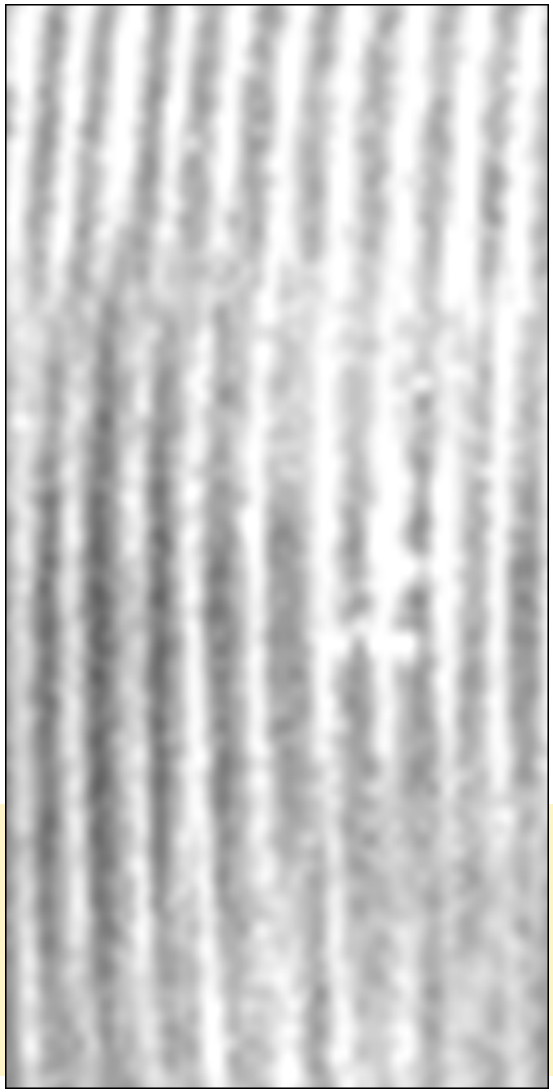
Residual grind marks (circular)



- Local slope error
  - AOS achieved 0.25-second rms for scale lengths > 1mm.
- Geometry error
  - AOS achieved less than 2-micron departure to perfect shape.
- Metrology Method
  - Many challenges still exist in this area.

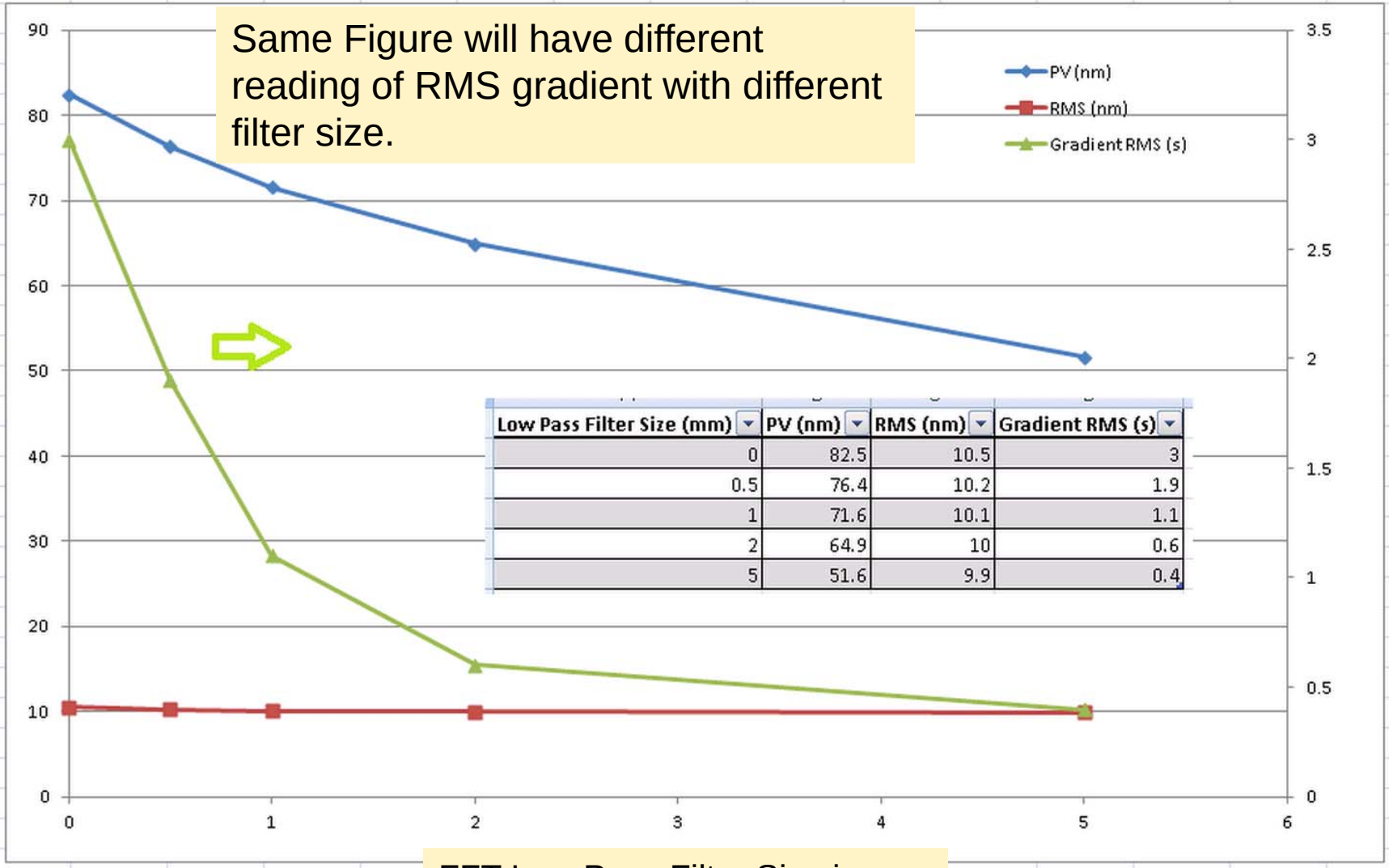
# Mid-Spatial Feature Affects X-Ray Image Quality

- X-Ray imaging optics will see the slope at higher spatial resolution.
- Control of MSF errors at high spatial resolution to date is challenge for XRAY optics
- High spatial resolution and low noise metrology method is necessary.



Micro-trenches from sub-aperture polishing are revealed with x-ray imaging due to local slope at 1mm scale.

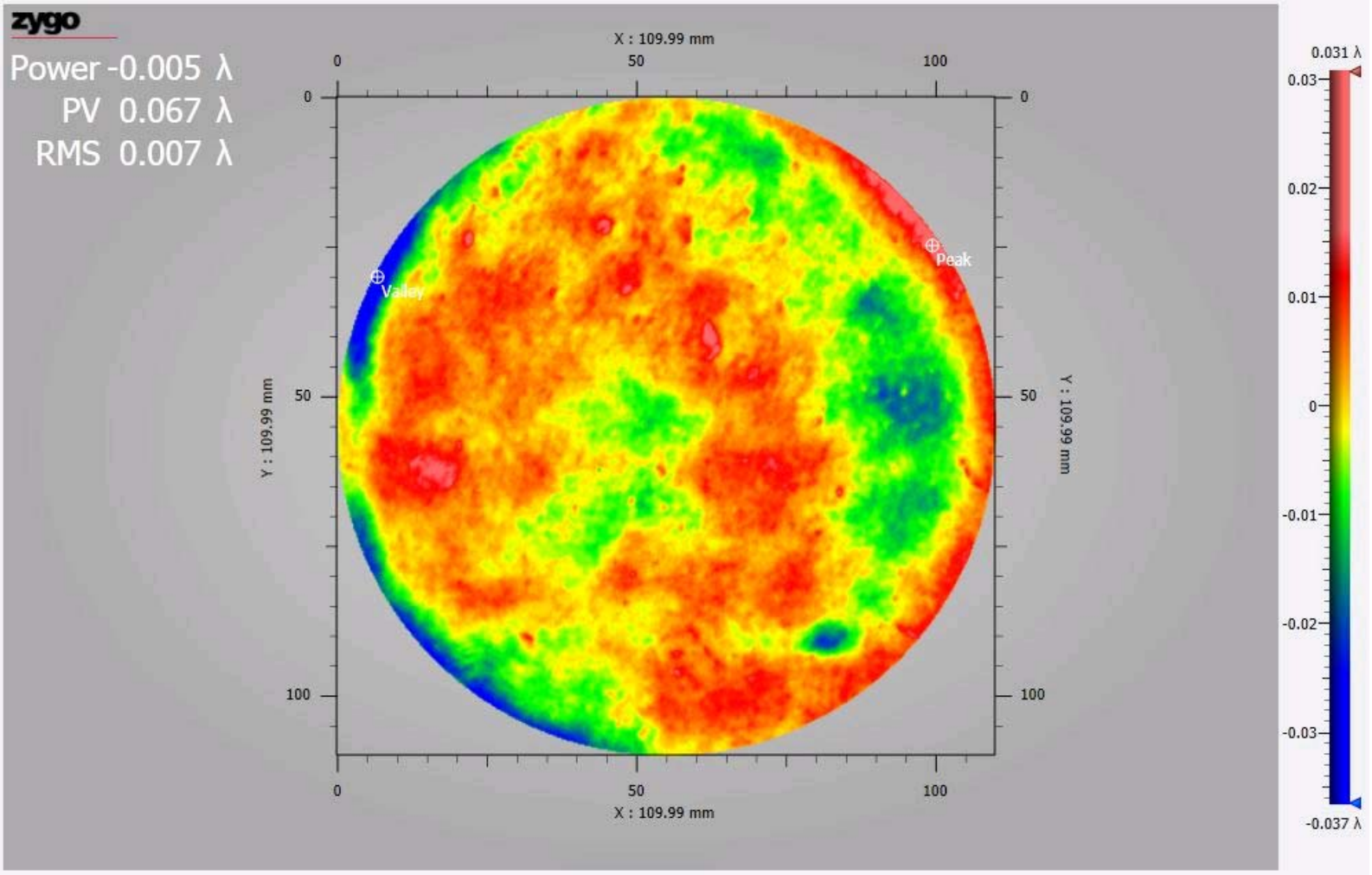
Same Figure will have different reading of RMS gradient with different filter size.



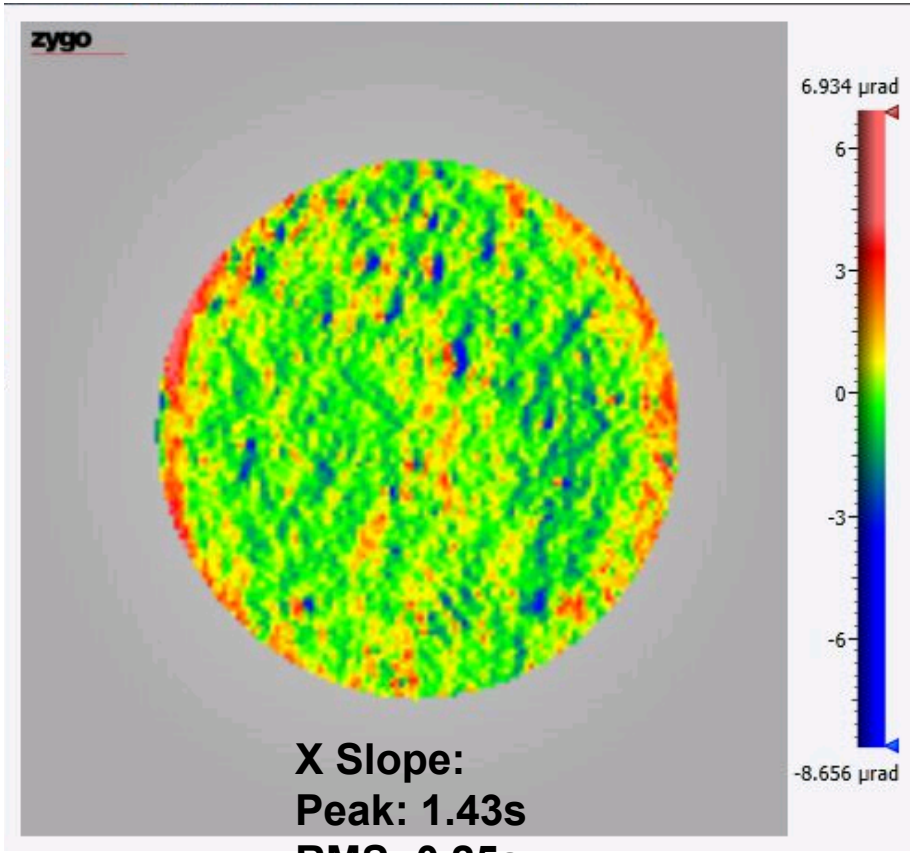

| Low Pass Filter Size (mm) | PV (nm) | RMS (nm) | Gradient RMS (s) |
|---|---|---|---|
| 0 | 82.5 | 10.5 | 3 |
| 0.5 | 76.4 | 10.2 | 1.9 |
| 1 | 71.6 | 10.1 | 1.1 |
| 2 | 64.9 | 10 | 0.6 |
| 5 | 51.6 | 9.9 | 0.4 |

FFT Low Pass Filter Size in mm

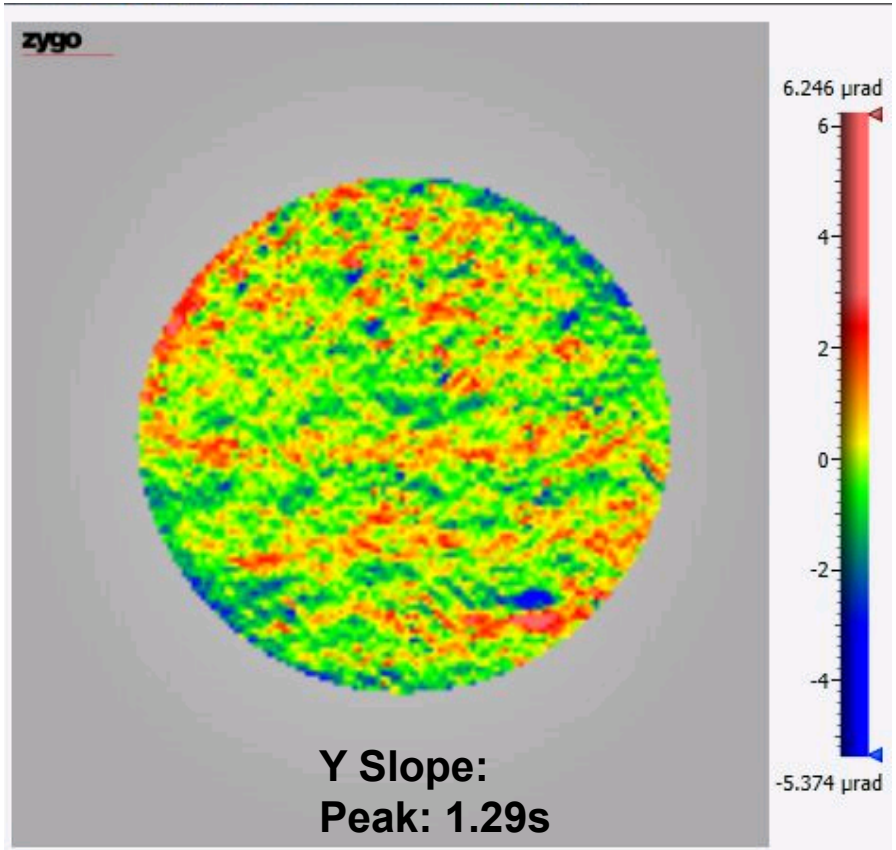
# Recent Result: F/3.6, 20 Degree Parabola



# Significant Improvement on Slope




**X Slope:**
**Peak: 1.43s**
**RMS: 0.25s**




**Y Slope:**
**Peak: 1.29s**
**RMS: 0.22s**

Shown with ~1mm integration length for slope calculation.

# Conclusions

- AOS has employed a multi-step approach to make asphere surface which employs Zeeko robotic grinding and polishing, MSF process modeling, MSF preventive process design, MSF mitigation, and advance optical interferometry.
- Our process capability is evolving at a fast rate and can be employed on aspheres from F/0.6 to F/45 over sizes from 1 inch to 1 meter. With **NO** modification, it will be suitable for manufacturing grazing incident optics.
- Low Mid-spatial error results at sub-aperture polishing can be reduced to be at comparable to spherical optics even with large asphere departures. This allows us to produce near perfect asphere and x-ray optics.
- Thanks NASA's funding on grinding and MSF mitigation development in 2011. We are looking forward in production opportunity of high end x-ray optics.